10/589225
IAP11 Rec'd PCT/PTO 11 AUG 2006

Method for calibration of step length and arrangement utilizing the method

The invention relates to a method for measuring the length of a person's steps, in which method the distance covered and the number of steps used is measured. The invention also relates to a measuring arrangement in which the method is applied and a sound transmitter and a sound receiver used in the measuring arrangement.

The quantity and quality of exercise practiced by a person has a significant effect on the person's health. For example, the probability of heart diseases can be reduced by the kind of exercise that stresses the heart in a suitable way. A connection is also known to exist between osteoporosis and the practicing of different kinds of sports. The consumption of superfluous energy stored in the body by means of physical exercise is an object of increasing interest in weight control. Measuring or calculating the level of stress of the exercise is thus an important factor with regard to analyzing the health effects.

The performance of physical exercise can be observed by many kinds of methods and arrangements. One well-known way is to measure the heart rate during the exercise/stress by a heart rate monitor, the readings of which can be examined either in real time or by means of data collected in some data collecting device. By a heart rate monitor it can be reliably found out, for example, if the exercise is of the kind that strengthens the heart. By the information of the heart rate monitor it is also possible to calculate an estimation of the amount of energy consumed during the exercise.

On the other hand, it is known from the patent application FI20012547 that by measuring the accelerations created in the bones of a person during the exercise it is possible to anticipate the direction in which the mass of bones will develop. The accelerations influencing the bones vary in different kinds of exercise. For example, higher acceleration peaks are created in running and jumping than in slow walking.

Weight control is also one of the most central factors having an effect on health. If more energy from the food eaten is stored in the tissues of a person than is consumed daily on an average, it inevitably leads to an increase of the weight. Therefore, there is an obvious need for a kind of an easy-to-use calorimeter, which measures the energy consumption of a person continuously and easily.

However, utilizing merely some average measurement information can be problematic. Even in the same kind of exercise there can be significant differences between different persons. By using only some average information describing exercise, gathered from a large mass, it is possible to arrive at erroneous conclusions for some persons.

The amount of energy consumed by a person is influenced both by the person's weight and the form of exercise used and its intensity. In walking or running, energy consumption can be forecast on the basis of the speed of the person moving. The speed can be determined by the length and rate of steps, for example. If the length of steps used by the person in walking, for example, is known, it can be used to calculate a forecast of the person's energy consumption during a certain exercise. The length of steps can naturally be measured and calculated entirely manually. Then the calculation result obtained only needs to be saved in a data collection system for later use. However, the manual system is rigid. It requires preliminary preparations with distance measurements. The calculation of the length of steps must be carried out as a separate procedure, and the calculation result obtained must also be separately saved in a data storage device.

The length of steps can also be determined by using optical means. In optical measuring methods it is common to use the infrared range. However, the speed of light is so high that it sets strict requirements for the measuring equipment used. Even a small timing error in the determination of the reception of the light pulse causes a significant error in the determination of the place of transmission of the light pulse. Due to the strict accuracy requirement for timing, optical step length measuring equipment is expensive to manufacture.

The GPS technology (Global Positioning System) can also be utilized in measuring the length of steps. The accuracy varies depending on the reception equipment and the accuracy allowed by the service provider. However, the accuracy achieved in determining the point of reception can be some fractions of a meter. GPS positioning equipment is rather expensive, and therefore a step measuring system implemented by it would become expensive.

The objective of the present invention is to provide a method and a device arrangement, by which the step length of a person can be measured without manual measurements, calculations and saving of data by a simple and inexpensive device arrangement.

The objectives of the invention are achieved by a procedure and device arrangement, in which the distance covered by the person is measured by means of timed sound pulses received in a fixed place. The person carries along a sound transmitter, which transmits the timed sound pulses. The transit time of the pulse can be calculated from the moment of reception of the sound pulses, and the distance of the person carrying the transmitter at the moment of reception of a certain sound pulse can be determined from it. The speed at which the person is moving can also be estimated from the reception moments of consecutive pulses. The number of steps taken by the person is advantageously measured by an acceleration transducer provided in connection with the sound transmitter.

The method according to the invention has the advantage that the length of the steps can be determined without manual measurement and calculation operations.

In addition, the invention has the advantage that the device system utilized is simple and inexpensive to manufacture.

Furthermore, the invention has the advantage that the result of the determination of the length of steps is saved directly in a device functioning as the receiver of the sound pulses, which device can be a terminal device of a cellular network.

The method according to the invention is characterized in that

– the distance covered is measured by transit time measurement of sound frequency pulses, in which the transit time is measured between the moving person and a fixed point, and in which before measuring the distance covered

  – the measuring time used for measuring the length of steps is determined, and

  – the clocks of the transmitting means and receiving means of the sound pulses are synchronized, whereby the receiving means of the sound pulses know both the moments of reception of the sound pulses and the moment of transmission of each sound pulse, and that

– the number of steps taken during the measurement is measured by the acceleration transducer carried along by the person.

The step length measurement arrangement according to the invention is characterized in that

– the distance covered is arranged to be measured by transit time measurement of sound frequency pulses, in which the transit time is arranged to be measured between the moving person and a fixed point, and in which before measuring the distance covered

– the measuring time to be used has been determined, and

– the clocks of the transmitting means and receiving means of sound pulses have been synchronized, whereby the reception means of sound pulses have knowledge of both the moments of reception of the sound pulses and the moments of transmission of each sound pulse, and in which measurement arrangement

– the number of steps taken during the measurement of the length of steps is arranged to be calculated from the acceleration pulses caused by the steps, measured by the acceleration transducer carried along by the person.

The sound receiver according to the invention, used in the determination of the length of steps, is characterized in that it comprises

– a user interface for inputting the initial information of the step length measurement and for presenting the measurement result of the calculated length of steps

– a sound frequency receiver for receiving and indicating a sound signal of essentially the frequency of 1 000–2 000 Hz

– a central processing unit, a memory and a clock function for calculating the transit time of the received sound pulse and for performing the distance calculation on the basis of the transit time, and

– a power source.

The sound transmitter according to the invention, used in the determination of the length of steps, is characterized in that it comprises

– a user interface for starting the measuring of the length of steps

– a sound frequency transmitter for transmitting a sound signal having essentially the frequency of 1 000–2 000 Hz

– a central processing unit, a memory and a clock function

  – for transmitting the sound pulse used in the measurement at the intervals of a certain delay

  – for detecting the end of the time defined for the measurement

  – for transmitting the measurement end pulse

– means for detecting the acceleration peak caused by the step and for saving the number of the acceleration peaks detected, and

– a power source.

Some preferred embodiments of the invention are set forth in the dependent claims.

The basic idea of the invention is the following: The distance covered by the person is measured against some fixed point. In the fixed point there is advantageously a receiver which receives sound pulses. Hereinafter, this receiver will be called a sound receiver. A sound transmitter carried along by a moving person sends steep-edged sound pulses preferably in the frequency range of 1 000–2 000 Hz. The person performing the measurement carries the sound transmitter advantageously on his/her waist. When the measurement begins, the clocks of the portable sound transmitter and sound receiver are synchronized. The portable sound transmitter gives the first sound signal, which starts the clocks of both the portable sound transmitter and the sound receiver. The starting sound signal is advantageously given by pressing a button in the sound transmitter while the person is standing still. After this, the person moves at an even speed away from the fixed reception point. All the time, the sound transmitter gives a new sound pulse at even, predetermined intervals. The interval of the sound pulses can be advantageously about 200 ms. Since the clocks of the sound transmitter and receiver are synchronized, it is possible to calculate by means of the reception moment of the sound pulse and the sequence number of the received pulse how far the sound transmitter carried by the person is at the moment of reception of a certain pulse, because the speed of sound in the air is known. The sound transmitter carried by the person advantageously also comprises at least one acceleration transducer. The steps and their exact moments can be registered by it during the measurement period. The average length of steps is obtained by dividing the distance advanced during all the consecutive steps of the measurement period by the number of steps. The calculation result obtained is preferably saved in the sound receiver. The sound receiver is advantageously part of a terminal device of a cellular network.

In the following, the invention will be described in more detail. Reference will be made to the accompanying drawings, in which

Fig. 1 shows an example of a measuring arrangement according to the invention for measuring the length of steps,

Fig. 2 shows the effect of wind on the measuring arrangement,

Fig. 3 presents, as an exemplary flow chart, the main steps of the method according to the invention,

Fig. 4a shows the main parts of the sound receiver according to the invention by way of example, and

Fig. 4b shows the functional main parts comprised by the sound transmitter according to the invention by way of example.

Fig. 1 shows a step length measuring arrangement according to the invention by way of example. Reference number 1 denotes a person who is determining the length of his/her steps. The measurement of the length of steps may concern either walking or running. There can naturally be different kinds of both forms of exercise, such as slow walking, normal walking or fast walking. By the method according to the invention, the measurement of the length of steps can preferably be performed separately on each of the forms of exercise mentioned. In the example of Fig. 1, the person 1 performing the measurement has moved at an even speed from point A to point B. The distance between the points A and B is denoted by the reference S. When the distance S covered by the person is known, the length of steps of the form of exercise used can be calculated by means of the steps used for the distance covered.

In the measuring system according to the invention, the distance S moved by the person is determined by means of sound pulses transmitted at regular intervals. The steps taken by the person moving are advantageously detected by measuring the accelerations caused by the steps. The transmitter 11 of sound pulses according to the invention comprises means for transmitting sound pulses at certain time intervals and advantageously at least one acceleration transducer.

The sound frequency of the sound pulses to be transmitted is advantageously in the order of 1 000–2 000 Hz. The pulses 12a, 12b and 12c are transmitted at the rate of a few pulses per second. The pulses 12a, 12b and 12c can be transmitted at the intervals of 200 ms, for example. The duration of the sound pulse to be transmitted is preferably under 100 ms. At such a pulse ratio, the consecutive pulses 12a, 12b and 12c can be easily separated from each other. The sound transmitter 11 according to the invention transmits sound pulses preferably for a predetermined time after its starting, after which the measuring is stopped. The

operating time can be 10 seconds, for example. When the 10 seconds have passed since the starting of the measurement, the sound transmitter 11 according to the invention sends an ending sound signal, after which the transmission of sound pulses ends.

The person 1 carries, preferably on his/her waist, a sound transmitter 11. The height of the sound transmitter 11 from the ground surface 2 is denoted by the letter H. In the example shown by Fig. 1, the sound pulse 12c is arriving at the sound receiver 10. Samples are taken from the received analogue sound pulse advantageously at the frequency of 8–16 kHz. Then the time of arrival of the front edge of the sound pulse to be received, such as 12c, can be determined accurately.

Because the sound transmitter 11 and the sound receiver 10 are at different heights from the ground surface 2, the sound must move a longer distance S' than the distance S which is actually covered by the person 1. The direction in which the sound propagates from the sound transmitter 11 to the sound receiver 10 forms a variable angle α with the ground surface 2. The size of the angle α determines how large the measurement deviation (S'-S) from the actual distance covered S is. The further the sound receiver 10 is from the sound transmitter 11, the smaller the angle α becomes. When the distance S of the moving person increases, the distance S' covered by the sound approaches the actual distance A–B on the ground level, reference S in Fig. 1. Table 1 presents a few examples of how the distance S of the sound receiver 10 from the sound transmitter 11 and the height H of the sound transmitter 11 from the ground level influence the magnitude of the error/deviation occurring. However, the error can be taken into account in the calculation of the distance and corrected by a suitable correction function, when required.

Table 1: The effect of the height H of the person and the covered distance S on the measurement

Heigth H	1.50 m		1.60 m		1.70 m		1.80 m		1.90 m	
Distance S (m)	abs (m)	rel. (%)	abs (m)	rel. (%)	abs (m)	rel. (%)	abs (m)	rel. (%)	abs (m)	rel. (%)
1	0.35	35.5	0.39	38.6	0.43	42.8	0.47	47.2	0.52	51.6
2	0.19	9.7	0.22	10.9	0.25	12.3	0.27	13.6	0.30	15.1
4	0.10	2.5	0.11	2.8	0.13	3.2	0.14	3.6	0.16	4.0
5	0.08	1.6	0.09	1.8	0.10	2.1	0.12	2.3	0.13	2.6
9	0.04	0.5	0.05	0.6	0.06	0.6	0.06	0.7	0.07	0.8
10	0.04	0.4	0.05	0.5	0.05	0.5	0.06	0.6	0.06	0.6

Table 1 indicates that if the person advances 10 m or more away from the sound receiver 10 during the step length measurement, the relative error of the measurement is only fractions of one per cent. If the person does not advance further than 5 m from the sound receiver 10, a suitable correction function should be used. The correction function must also be utilized in a situation where the location and/or speed of the person at the moment of reception of each received sound pulse is wanted to know.

Fig. 2 shows the effect of wind in the measurement arrangement according to the invention. The direction and speed of the wind have an effect on the speed of the propagating sound pulses. In Fig. 2, the line segment A–B indicates the direction in which the test person 1 moves. The arrow W indicates the prevailing direction and speed of the wind. The direction of the wind W forms an angle ß with the movement of the test person 1. Table 2 shows how the speed and direction of the wind influence the speed of sound propagating in the air.

Table 2: The effect of the speed and direction of the wind on the speed of sound

Angle β	Speed of wind 0 m/s	Speed of wind 10 m/s	Speed of wind 20 m/s
0	331.1	341.3	350.9
15	331.1	330.0	330.0
45	331.1	324.7	317.5
75	331.1	321.5	311.5
90	331.1	320.5	310.6
115	331.1	321.5	311.5
135	331.1	323.6	315.5
165	331.1	326.8	321.5
180	331.1	320.5	310.6

According to Table 2, it is clear that the direction and speed of the wind must be taken into account in the measurement. At the wind speed of 10 m/s, which can be considered a hard wind, the direction of the wind can have an effect of over 6% on the speed of sound detected. So, in hard wind conditions, the direction of the wind must be taken into account during testing.

The propagation speed of sound in the air is also influenced by the prevailing humidity and temperature of air. Their effect is presented in Table 3.

Table 3: The effect of the humidity and temperature of air on the speed of sound

Temperature Humidity %	-30 C^0 m/s	-20 C^0 m/s	-10 C^0 m/s	0 C^0 m/s	+10 C^0 m/s	+20 C^0 m/s	+30 C^0 m/s
0	312.8	319.2	325.4	331.5	337.5	343.4	349.3
15	–	–	325.4	331.5	337.5	343.4	349.4
30	–	–	325.4	331.5	337.5	343.6	349.8
45	–	–	325.4	331.5	337.6	343.9	350.3
60	–	–	325.4	331.5	337.8	344.1	350.7
75	–	–	325.4	331.6	337.9	344.4	351.1
90	–	–	325.4	331.6	338.0	344.6	351.1

From Table 3, it is found out that temperature has a stronger effect on the speed of sound than air humidity. Therefore, the temperature prevailing during the step measurement must also be taken into account in the measurement situation. The effect of humidity on the speed of sound is so small that it can be ignored.

The following variables must then be taken into account in the measurement situation for improving the accuracy of the measurement: the prevailing temperature, the prevailing direction of the wind during the measurement, the speed of the wind and the height of the person performing the measurement. This information can advantageously be fed to the sound receiver 10, in which a suitable program application according to the invention has been saved. Indoors or in otherwise windless conditions, the temperature and the height of the person are usually sufficient information. The joint effect of the weather conditions can also be calculated programmably, if separate calibration is carried out in the conditions prevailing on a known passage. When the information has been saved in the sound receiver 10, the measurement of the length of steps can be started. The saved environmental values and the given values are utilized when calculating the location of the person 1 at the moment of reception of each sound pulse. The program application according to the invention performs the calculations required in the measurement of the length of steps. When required, the calculated results are shown on the display of the sound receiver 10. The measurement result of the length of steps obtained is saved in the memory of the sound receiver 10 for later use.

Fig. 3 shows the main steps of the step length measurement according to the invention as an exemplary flow chart. Preparatory measures are performed in step 300. These include, among other things, the synchronization of the clocks of the sound transmitter 11 and the sound receiver 10. By means of synchronization, the sound receiver 10 can determine when the sound pulse transmitted by the sound transmitter 11 is received. In addition, after synchronization the sound receiver 10 can determine when the sound pulse was transmitted and which of the sound pulses belonging to the measurement in sequence it is.

In step 300, the environmental information having an effect on the speed of sound is also fed to the sound receiver 10: temperature, wind direction and speed. The height of the person is also fed in order to be able to correct the geometrical error in a calculatory manner.

In step 310, the step length measurement is started. The starting is advantageously performed by pressing the start button in the sound transmitter 11. Then the sound transmitter 11 starts transmitting sound pulses and the acceleration transducer advantageously integrated with it starts the acceleration measurements.

Alternatively, the starting is carried out by the sound receiver 10, in which case the starting information must be wirelessly transferred to the sound transmitter 11 in order to start it. The starting time of each step is recognized from the acceleration transducer information. The moment of transmission of the first sound pulse is marked in the measurement process as the moment 0 s, which can be denoted by t_0, for example. After the transmission of the sound pulse, the operation of the process according to the invention is branched into two separate devices: a sound receiver 10 and a sound transmitter 11. This branching is illustrated by a dashed arrow in Fig. 3.

In step 320, a sound pulse is received in the sound receiver 10 at the moment t_1, which differs from the moment of transmission t_0 of the sound pulse. The difference $t_1 - t_0$ corresponds to the transit time required by the sound for travelling from the sound transmitter 11 to the sound receiver 10. In step 321, an estimate of the distance S of the person 1 is calculated on the basis of the given data and the measured transit time. When the estimate of the distance S is calculated, the given data saved in step 300, which have an effect on the speed of sound and the given data concerning the size of the person performing the measurement are taken into account during calculation.

From the reception moments of two consecutive sound pulses it is also possible to calculate the velocity V of the person 1 between the received sound pulses.

In step 322, the calculation results S and V are saved in the memory of the sound receiver 10. After saving, the sound receiver 10 stays to wait for the next sound pulse, which can be either the next measurement pulse or a sound pulse indicating the end of the step measurement.

In the sound transmitter 11, the operation continues after the first transmitted sound pulse in the following manner. The transmission of the sound pulse is followed by step 312. In this step 312 the value N of the pulse calculator in the sound transmitter 11 is increased by one. After the transmission of the first pulse, the value of the pulse calculator N is thus 1. After the next transmitted sound pulses, the value of the pulse calculator N always increases by one.

A comparison is carried out in step 313, in which it is examined whether the value of the pulse calculator N multiplied by the delay τ is smaller than a preset measuring time M. The delay τ corresponds to the time interval of the sound pulses to be

transmitted, and it is advantageously 200 ms. At the beginning of the measurement, the measuring time M to be used can be set as desired. It can be 10 seconds, for example. If the comparison in step 313 gives the result YES, the procedure moves to step 314. A delay element from which the signal comes out after a certain delay τ is used in step 314. This delayed signal causes the transmission of a new sound pulse at the moment $t_0 + \tau$. After this, the steps 311, 312, 313 and 314 are repeated so many times that finally the result NO is obtained in step 313. Then the preset measuring time M has expired and the step length measurement can be ended.

The end of the measurement is indicated by sending an ending sound pulse in step 330. The ending sound pulse differs from the actual measurement sound pulses in a way which can be recognized by the sound receiver 10.

In step 340, the sound receiver 10 receives a sound pulse indicating the end of the measurement from the sound transmitter 11. After receiving this ending sound pulse, the sound receiver 10 preferably saves the latest calculation results in its memory: the number and time of the steps, the distance S covered during them and the average speed V. When the sound transmitter 11 has transmitted an ending pulse, it preferably also transmits immediately the number of steps measured by it through a separate wireless link to the sound receiver 10. The sound transmitter measures the number of steps advantageously by an acceleration transducer in it. The number N of acceleration maximums obtained from the acceleration transducer corresponds to the steps taken.

In step 350, the measured length of steps is shown on the display of the sound receiver 10, when desired. The length of steps measured by the method according to the invention can be immediately utilized in other possible exercise-related applications.

Fig. 4a shows some functional parts comprised by the sound receiver 10 according to the invention by way of example. The sound receiver 10 includes a power source 44, which is advantageously a battery. The capacity of the power source 44 is so high that it can guarantee a long time of operation to the sound receiver 10.

The user can control the sound receiver 10 through the user interface 43. By it, the environmental and user information needed in the measurement method accord-

ing to the invention, which have an effect on the accuracy of the measurement, can be fed to the sound receiver 10. The user interface 43 preferably also includes some means suited for presenting the length of steps. Such means can be a display unit and/or a loudspeaker, for example.

The operation of the sound receiver 10 is controlled by a processor unit 41. It preferably comprises a central processing unit (CPU) and a memory having a fixed connection with it. The memory belonging to the processor unit 41 can be implemented by prior art memory units. The processor unit 41 also includes a clock function, which is utilized in the determination of the reception moment of sound pulses.

An application program according to the invention, utilized in the step length measurement, is run in the processor unit 41. This program application advantageously comprises steps 320–350 of the flow chart 3. The program application according to the invention has advantageously been saved in the memory belonging to the processor unit 41. The environmental and user information, step 300 in Fig. 3, can be saved through the user interface 43 in the same memory in a way that the application program according to the invention can utilize them.

The sound receiver 10 also includes reception means 42 for the sound pulses. They comprise a microphone unit and signal processing means, which process the received analogue sound signal into a digital signal. The analogue signal is converted into a digital signal by an A/D converter, the sampling frequency of which is preferably in the order of 8–16 kHz. The received signal samples are taken to the processor unit 41, which makes the decision on the reception moment of the sound pulse. The processor unit 41 also knows what the sequence number of each received sound pulse is, as counted from the first received sound signal. From this information it can draw a conclusion on the moment of transmission of the sound pulse received by it. The transit time used by the sound pulse is obtained by subtracting the moment of transmission of the sound pulse from the moment of reception.

In an advantageous embodiment of the invention, the sound receiver 10 is a terminal of a cellular network, into which a program application according to the invention, suitable for the step length measurement, has been loaded.

Fig. 4b shows, by way of example, the functional main parts of the sound transmitter 11 carried along by the person performing the measurement. It includes a power source 49, the capacity of which enables the transmission of sound pulses with a sufficient level. The person 1 performing the measurement controls the sound transmitter 11 by the user interface 47. The user interface 47 preferably comprises means for starting the synchronization procedure of the clocks of the sound transmitter 11 and receiver 10 and means for starting the actual measurement.

The transmission of the sound pulses is controlled by a processor unit 45, which comprises a central processing unit (CPU), a memory and a clock function. A part of the application program according to the invention for determining the step length, steps 310–313 and step 330 in Fig. 3, has advantageously been saved in the memory belonging to the processor unit 45. These steps of the method according to the invention are performed in the processor unit 45 of the sound transmitter 11.

The sound transmitter 11 also comprises means 46 for transmitting sound pulses of a predetermined length. These means 46 comprise an oscillator, advantageously 1 000–2 000 Hz, for generating a sound signal. The frequency of the sound signal, the moment of transmission and the length of the transmission are specified by an instruction given by the processor unit 45. In an advantageous embodiment of the invention, sound pulses are transmitted at intervals of 200 ms. The length of the pulses is in the order of 100 ms.

The sound transmitter 11 preferably comprises at least one acceleration transducer 48. The steps N taken during the step length measurement can be calculated from the measurement information, advantageously the maximum values of acceleration, of the acceleration transducer 48. After the measurement, the detected number of steps N is advantageously indicated either on a display belonging to the user interface 47 of the sound transmitter 11, or the number of steps N is transferred by some prior art wireless data transfer link to the sound receiver 10. These means required in data transfer are not shown in figures 4a and 4b. Examples of possible, suitable data transfer methods are an IR link or a Bluetooth connection.

In a preferred embodiment of the invention, the sound transmitter 11 is a terminal of a cellular network, into which a program application according to the invention, suitable for step length measurement, has been loaded.

Some preferred embodiments of the method and device arrangement according to the invention have been described above. However, the invention is not limited to the embodiments described. The inventive idea can be applied in such a way, for example, that the functional roles of the transmitter and receiver are changed. Then the person carrying out the step length measurement carries the receiver, and the transmitter is at a fixed point. In addition, the inventive idea can be applied in numerous ways within the limits set by the claims.